

Be it known that we; Michelle Simkulet, a citizen of the United States, residing in the State of New York and having a mailing address at 402 Baker Avenue, Cohoes, NY 12047; Jason Smith, a citizen of the United States, residing in the State of New York and having a mailing address at 14 Youngs Place, Latham, NY 12110; Ronald Gamache, a citizen of the United States, residing in the State of New York and having a mailing address at 42 Old Troy Road, East Greenbush, NY 12061; and Jiayin Ma, a citizen of the Peoples Republic of China, residing in the State of New York and having a mailing address at 33 Fox Hollow, Rensselaer, NY 12144 have invented an

Integrated panoramic and forward view endoscope

of which the following is a

#### **SPECIFICATION**

##### **Cross-reference to related application**

This application claims the benefit of U.S. provisional application number 60,462,951, filed April 15, 2003.

##### **5 Field of the invention**

This invention relates to the field of endoscopic imaging, and particularly to the imaging and illumination design of an endoscope that integrates on a single image plane a forward field of view (FFOV) and a panoramic field of view  
10 (PFOV), thereby providing the user a total field of view comprising the FFOV and the PFOV simultaneously.

##### **Background of the invention**

Current art in endoscope design typically provides a 35°  
15 total viewing angle that may be rotated elevationally by angles up to 70° using prisms and mirrors. Further the view may be rotated axially by means of sheaths containing additional prisms/mirrors. Wide-angle views up to 120° are known but such designs suffer from high distortion and  
20 difficult component fabrication due to the need for

aspherical or highly curved elements. For many medical procedures, such as nasal sinoscopy, the restricted viewing provided by current art endoscopes require that several endoscopes or different viewing angles be used at different points in the procedure. The act of withdrawing and inserting the endoscope, especially since the process may be somewhat blind, can be the cause of additional trauma to the patient. Panoramic imaging systems are known in the art but either do not have forward viewing or accomplish forward viewing in a different way than the current invention. U.S. patent #6,028,719 assigned to InterScience, Inc. discloses a general technique of integrating a forward view and a panoramic view utilizing a single reflector for the panoramic field of view.

There are many existing patents for optical systems that provide omnidirectional imaging. We believe we have some unique characteristics that are not covered in any existing patent and that provide a unique new capability to imaging systems and omnidirectional optical components in general. Jeffrey Charles has several U.S. patents on the subject including US patent 6,333,826 and US patent 6,449,103, BeHere Corporation has several US patents including US 6,392,687, US 6,424,377 and US 6,480,229, and Remote Reality has US patent 6,611,282.

The patents by Jeffrey Charles focus solely on the panoramic field of view, and efforts to maximize that field of view for near field applications. The Charles' patents include a frontal exclusion zone of about 60 degrees that can be tapered approaching the far field by the use of a torroidal-shaped reflector. Although this exclusion zone eventually disappears as a point where the boundaries of

the panoramic field meet, there is no account in the patent for the overlapping area past the point of convergence in the processing or interpretation of the image. The minor disclosure of including forward optics to image the frontal exclusion zone makes no mention of details of how to match the magnification or the relative F/# of the integrated images as well as a means of interpreting or processing the overlapping images. The mere inclusion of forward viewing lenses does not automatically lend itself to an easily interpretable image. The focus of the optical system is near field prior to the overlap. Although there is provision to include the forward viewing optics to image the frontal exclusion zone, there will only be one point (or one radial distance) in which the frontal zone and the panoramic zone exist with either no gap or no overlap.

The BeHere technology also concentrates on the panoramic field of view and only makes provisions to extend the panoramic view as far forward as possible by changing the shape of the reflector. By placing a dimple in the apex of the parabolic reflector, imaging beyond the secondary reflector is achieved in the far field. These inventions provide no means for forward imaging in the near field.

The Remote Reality invention is a super wide-angle panoramic imaging apparatus that claims up to a 260° vertical field of view using a two reflector configuration. The invention includes an undefined blind spot along the optical axis. The invention claims a single view point while also having a substantially flat and stigmatic image plane.

None of these omnidirectional viewing systems provide a means of incorporating the optical system in an endoscope or borescope.

## **5 Objects of the invention**

It is an object of the present invention to provide a means of integrating panoramic imaging capabilities with a forward viewing endoscope design.

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It is an object of the present invention to provide a means of integrating panoramic imaging capabilities with a forward viewing endoscope design utilizing a two reflector panoramic imaging component.

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It is an object of the present invention to provide an endoscope design capable of presenting a forward field of view and a panoramic field of view integrally on a single image plane.

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It is an object of the present invention to provide a total field of view that is upright and unreversed without need for extensive computer processing to accomplish said upright and unreversed field of view.

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It is an object of the present invention to provide an endoscope design in which the boundaries of the forward field of view and panoramic field of view can be customized to fit to specific application needs.

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It is an object of the present invention to provide illumination means for a forward field of view and a panoramic field of view of an endoscope.

It is an object of the present invention to provide an endoscope capable of an integrated panoramic and forward view that can approach or exceed a solid angle of  $2\pi$  steradians.

It is an object of the present invention to provide the total field of view with low distortion, chromatic aberration, and viewpoint error. Such qualities are necessary to support diagnostic assessments during intended medical procedures.

### **Summary of the invention**

The objective of the present invention is to provide a single endoscope that provides a total field of view substantially greater than a hemisphere comprising a forward field of view and a panoramic field of view that are integrated on a single image plane. The invention is described with respect to a rigid endoscope, but the technology can be implemented on a flexible endoscope as well. The advantage of such an endoscope is that it would provide substantially more information to the physician than any single existing endoscope, and it can be used in place of multiple endoscopes with varying directions of view that are swapped throughout a procedure to provide different views. The invention can also be used in non-medical applications for inspection in closed or generally inaccessible spaces, such as the interior of jet engines.

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## **Brief Description of the Drawings**

The present invention, and the objects and advantages thereof, may best be understood by reference to the  
5 following detailed description and accompanying drawings in which:

Figure 1 is an overall view of the entire panoramic / forward view endoscope.

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Figure 2 is a longitudinal cross-section of the panoramic / forward view element and the endoscope objective.

Figure 3 is an axial cross section of the distal tip of the  
15 panoramic / forward view endoscope.

Figure 4 is an axial cross section of the relay and objective area of the panoramic / forward view endoscope.

20 Figure 5 is a first embodiment of the illumination distribution.

Figure 6 is a second embodiment of the illumination distribution.

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Figure 7 is a third embodiment of the illumination distribution.

Figure 8 is a fourth embodiment of the illumination  
30 distribution.

Figure 9 is a fifth embodiment of the illumination distribution.

Figure 10 is a sixth embodiment of the illumination distribution.

- 5 Figure 11 is a seventh embodiment of the illumination distribution.

### **Detailed Description**

- 10 The present invention provides an endoscope design that provides a total field of view substantially greater than a hemisphere comprising a forward field of view and a panoramic field of view that are continuous and integrated on a single image plane. The integrated fields of view are  
15 matched in magnification and brightness and there is a relatively seamless boundary between them with no blindspots or overlapping of the fields. The invention comprises panoramic and forward view imaging technology as well as panoramic and forward illumination technology. The  
20 invention is demonstrated on a rigid endoscope but the technology can be implemented on a flexible endoscope as well.

- The present invention is initially described with respect  
25 to Figure 1. Figure 1 shows the panoramic / forward view endoscope 100; which comprises a rigid endoscope eyepiece 110, housing of a rigid endoscope relay system 112, an illumination light guide port 114, housing of a endoscope objective 116, and housing of an integrated panoramic /  
30 forward viewing optical element 118.

The present invention utilizes a endoscope eyepiece 110, an endoscope relay system 112, and an illumination light guide

port 114 as known in the art. The improvements of the present invention to existing endoscope design are substantially provided in the endoscope objective 116 and the panoramic / forward viewing optical element 118. It is  
5 these elements that contribute to the unique  $2\pi+$  steradian (solid angle) viewing capabilities of the present invention. The layout of the modified endoscope objective 116 and the panoramic / forward viewing optical element 118 is shown in detail in Figure 2.

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As shown in Figure 2, the endoscope objective 116 is adjacent to the endoscope relay system 112. The endoscope objective 116 essentially comprises at least one focusing element. The figure depicts an embodiment comprising a  
15 first focusing element 120 and a second focusing element 122. The endoscope objective 116 serves to transform the converging ray bundles collected by the panoramic / forward view element 118 into telecentric input for the endoscope relay system 112.

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As shown in Figure 2, the endoscope objective 116 is adjacent to and receives optical input from the panoramic / forward viewing optical element 118. The panoramic / forward viewing optical element 118 essentially comprises a  
25 Panoramic Field of View (PFOV) optical element group 127, a Forward Field of View (FFOV) optical element group 136, and a focusing optical element group 139. The PFOV optical element group 127 essentially comprises two reflectors each having one mirror surface and each having a central  
30 aperture. A first reflector 124 is essentially a solid convex surface with the mirrored surface facing the distal end of the endoscope 100 and a central aperture. The first reflector 124 is symmetric about its central axis and



central aperture and is aligned along the optical axis 111. A cross-section of the first reflector 124, as depicted in Figure 2, would show the reflective surface to be a portion of a mathematical conic section, such as but not limited to a sphere or a parabola. A second reflector 126 with mirror surface facing the first reflector 124 can be planar, concave or convex. The surface geometry of both the first reflector 124 and the second reflector 126 can be optimized to obtain the desired PFOV 128 for a specific application.

The Forward Field of View (FFOV) optical element group 136 is comprised of a first lens group 132, a second lens group 134, and a third lens group 135 that images portions of the object substantially distal to the endoscope, i.e. the FFOV 130. The first lens group 132 gathers rays from a wide angle centered on the optical axis 111. The second and third lens groups 134, 135 focus and reduce the size of the gathered ray bundle so that it may pass through the apertures of the first and second reflectors 124 and 126.

The focusing optical element group 139 is centered along the optical axis 111 and is placed in line in the optical path between the PFOV optical element group 127 and the endoscope objective 116. It comprises at least two focusing optical elements, a first focusing optical element 137 and a second focusing optical element 138. The focusing optical element group 139 collects the panoramic field of view 128 from the secondary reflector 126 and the forward field of view 130 from the FFOV optical element group 136. It is the function of the focusing optical element group 139 to focus the two independent optical paths from the panoramic field of view 128 and the forward

field of view 130 as a coplanar image and to control the image aberrations on this coplanar image.

As shown in Figure 2, image information from the PFOV is  
5 collected by the first reflector 124 and is then reflected  
onto the second reflector 126. The second reflector 126  
then reflects the image information through the central  
aperture of the first reflector 124 to the focusing optical  
element group 139 and the endoscope objective 116. The  
10 forward field of view optical element group 136 passes the  
image information of the forward field of view 130 through  
the central aperture of the second reflector 126 and the  
first reflector 124 to the focusing optical element group  
139 and the endoscope objective 116. The geometries of the  
15 first and second reflectors 124 and 126 are designed to  
accept rays from the PFOV 128 and converge them with the  
FFOV 130 for coplanar focusing by the focusing optical  
element group 139 and the endoscope objective 116. The  
image information from the FFOV 130 and the PFOV 128  
20 provide an overall field of view of approximately 240  
degrees. The image information from the FFOV 130 and the  
PFOV 128 are matched substantially seamlessly on the image  
plane with virtually no overlap and no gap between them.  
The magnification and relative F# (or brightness) of the  
25 FFOV 130 and the PFOV 128 are matched as well.

As shown in Figures 2 and 3, disposed circumferentially  
about a substantial portion of the panoramic / forward  
viewing optical element 118 is a transparent cylindrical  
30 tube 141 that provides structural support and sealing for  
the system as well as a means for rays from the PFOV 128 to  
enter the system. It is known in the art that panoramic  
imaging systems comprised of spherical reflectors suffer

from so-called non-single viewpoint. Images from such non-single viewpoint systems cannot be processed to produce geometrically correct perspective views. For spherical reflector systems, each object point is viewed from a different viewpoint. Such variability of the viewpoint causes uncorrectable parallax in perspective views generated from such imagery. A further advantage of the transparent cylindrical tube 141 is to significantly reduce the size of the so-called viewpoint caustic and therefore parallax errors in the acquired perspective views. The viewpoint error can be brought to a minimum through the specification of the refractive index and thickness of the cylindrical tube 141.

Shown in Figures 2 and 4, as the panoramic / forward viewing element 118 is encircled by the transparent cylindrical tube 147, the endoscope relay 112 and modified endoscope objective 116 are circumferentially encased by endoscope luminal housing 140. The circumference of the endoscope luminal housing 140 is lined by endoscope illumination means 142. This illumination is distributed to the PFOV 128 and the FFOV 130. Figures 5, 6, 7, 8, 9, 10, and 11 show several options for distributing the illumination to the PFOV 128 and the FFOV 130.

Shown in Figure 5 is a first embodiment of the illumination distribution in the panoramic / forward view endoscope 100. In this embodiment the transparent cylindrical tube 141 comprises at least two sections, a distal section 150 and a proximal section 152 joined by an angled seam 154. In this embodiment a semi-transparent / semi-reflective coating could be introduced on the seam 154 so as to promote the proper distribution of the illumination between the

periphery of the endoscope 100 and the distal end of the endoscope 100. An adequate interface is established between the endoscope illumination means 142 and the transparent cylindrical tube 141, such as but not limited to optically transparent adhesive. This embodiment could benefit from the optional addition of a rigid and opaque internal support 156 for added structural support and as a means of preventing internal light leakage.

Shown in Figure 6 is a second embodiment of the illumination distribution in the panoramic / forward view endoscope 100. In this embodiment, a diffuse ring 158 of width R is on the outer circumference of the solid transparent cylindrical tube 141. The diffuse ring 158 is located distal to the PFOV 128 so as not to interfere with the imaging in the PFOV 128. In this embodiment an adequate interface is established between the endoscope illumination means 142 and the transparent cylindrical tube 141, such as but not limited to optically transparent adhesive. This embodiment could benefit from the optional addition of a rigid and opaque internal support 156 for added structural support and as a means of preventing internal light leakage.

Shown in Figure 7 is a third embodiment of the illumination means. In this embodiment, a diffuse ring 158 of width R is on the inner circumference of the solid transparent cylindrical tube 141. The diffuse ring 158 is located distal to the PFOV 128 so as not to interfere with the imaging in the PFOV 128. The diffuse ring 158 would radially scatter some of the light to illuminate the PFOV 128 that is propagating through the tube 141 to illuminate the FFOV 130. As in the first embodiment an adequate

interface is established between the endoscope illumination means 142 and the transparent cylindrical tube 141, such as but not limited to optically transparent adhesive. This embodiment could benefit from the optional addition of a rigid and opaque internal support 156 for added structural support and as a means of preventing internal light leakage.

Shown in Figure 8 is a fourth embodiment of the illumination distribution in the panoramic / forward view endoscope 100. In this embodiment, a curved notch 160 is on the outer circumference of the solid transparent cylindrical tube 141. The curved notch 160 is located distal to the PFOV 128 so as not to interfere with the imaging in the PFOV 128. The notch 160 is included to interrupt and divert the transmission of a portion of the illumination along the transparent cylindrical tube 141 and therefore allowing illumination to be distributed to the PFOV 128. As in the first embodiment an adequate interface is established between the endoscope illumination means 142 and the transparent cylindrical tube 141, such as but not limited to optically transparent adhesive. This embodiment could benefit from the optional addition of a rigid and opaque internal support 156 for added structural support and as a means of preventing internal light leakage. Alternatively the notch may be an angled notch 162 as shown in the fifth embodiment in Figure 9.

Figure 10 shows a sixth alternative embodiment of the illumination means. In this embodiment a portion of the illumination fibers continue along the inner circumference of the transparent tube to illuminate the forward field of view. The remainder of the illumination fibers end at the

proximal end of the transparent tube to distribute light to the panoramic field of view. The transparent cylindrical tube 141 comprises at least two sections, a distal section 150 and a proximal section 152 joined by an angled seam

5 154. In this embodiment a reflective coating is introduced on the seam 154 so as to promote the proper distribution of the illumination to the periphery of the endoscope 100. An adequate interface is established between the endoscope illumination means 142 and the transparent cylindrical tube 10 141, such as but not limited to optically transparent adhesive.

Figure 11 shows a seventh alternative embodiment of the illumination means. In this embodiment a portion of the 15 illumination fibers continue along the inner circumference of the transparent tube to illuminate the forward field of view. The remainder of the illumination fibers end at the proximal end of the transparent tube to distribute light to the panoramic field of view. The transparent cylindrical 20 tube 141 comprises at least two sections, a distal section 150 and a proximal section 152 joined by a seam 154. In this embodiment a reflective coating is introduced on the seam 154 and the proximal section 152 is made entirely of diffuse glass with a light blocking barrier 156 on its 25 inner diameter so as to promote the proper distribution of the illumination to the periphery of the endoscope 100. An adequate interface is established between the endoscope illumination means 142 and the transparent cylindrical tube 141, such as but not limited to optically transparent 30 adhesive.

While only certain preferred features of the invention have been illustrated and described, many modifications, changes